

(a) An Electron And A 0.0240 Kg Bullet Each Have A Velocity Of Magnitude 490 M/s, Accurate To Within

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Introduction

Understanding the motion and energy of particles and objects moving at high velocities is a fundamental aspect of physics. In this context, examining the case of an electron and a bullet, both traveling at the same speed of 490 meters per second (m/s), provides insight into concepts such as kinetic energy, relativistic effects, and measurement precision. While the electron is a subatomic particle with negligible mass compared to macroscopic objects, the bullet is a tangible object with a measurable mass. The phrase “accurate to within” indicates the importance of measurement uncertainties and how they influence our understanding of the system’s dynamics. This article explores these concepts in detail, providing a comprehensive analysis of the motion, energies, and measurement considerations associated with both the electron and the bullet.

Properties of the Electron and the Bullet

Mass of the Electron

- The electron has a fundamental mass of approximately 9.109×10^{-31} kilograms.
- Its tiny mass means relativistic effects are negligible at non-relativistic speeds like 490 m/s.
- The electron's behavior is predominantly governed by quantum mechanics and electromagnetic interactions.

Mass of the Bullet

- The given mass of the bullet is 0.0240 kg, or 24 grams.
- This mass falls within typical ranges for small caliber bullets used in firearms.
- The macroscopic nature of the bullet allows classical mechanics to be applied with high accuracy at this speed.

Velocity and Its Significance

Velocity Magnitude and Its Implications

- Both the electron and the bullet are moving at a speed of 490 m/s.
- While 490 m/s is fast for everyday objects, it is well within the classical regime for the bullet.
- For the electron, such a velocity is also non-relativistic, but quantum effects are more significant.

Measurement Accuracy

- The phrase “accurate to within” typically refers to the uncertainty or error margin in velocity measurement.
- For example, if the velocity is given as $490 \text{ m/s} \pm 1 \text{ m/s}$, the true value may lie within 489 to 491 m/s.
- This uncertainty affects calculations of kinetic energy and other derived quantities.

Kinetic Energy Calculations

Classical Kinetic Energy Formula

- Kinetic energy (KE) is given by: $KE = (1/2) m v^2$
- Applicable for both macroscopic objects and subatomic particles at non-relativistic speeds.

Calculating for the Bullet

- Mass, $m = 0.0240 \text{ kg}$
- Velocity, $v = 490 \text{ m/s}$
- $KE = (1/2) \times 0.0240 \text{ kg} \times (490 \text{ m/s})^2$
- $KE \approx 0.0120 \text{ kg} \times 240100 \text{ m}^2/\text{s}^2 \approx 2881.2 \text{ Joules}$

Calculating for the Electron

- Mass, $m \approx 9.109 \times 10^{-31} \text{ kg}$
- Velocity, $v = 490 \text{ m/s}$
- $KE = (1/2) \times 9.109 \times 10^{-31} \text{ kg} \times (490 \text{ m/s})^2$
- $KE \approx 4.5545 \times 10^{-31} \text{ kg} \times 240100 \text{ m}^2/\text{s}^2 \approx 1.093 \times 10^{-25} \text{ Joules}$

Relativistic Considerations

When Are Relativistic Effects Significant?

- Relativistic effects become important when velocities approach the speed of light ($\sim 3 \times 10^8 \text{ m/s}$).
- Here, $v = 490 \text{ m/s}$ is negligible compared to c , so classical mechanics suffices.

Relativistic Kinetic Energy

- For completeness, the relativistic kinetic energy is $KE = (\gamma - 1) mc^2$, where $\gamma = 1 / \sqrt{1 - v^2/c^2}$.
- At 490 m/s, $\gamma \approx 1 + (v^2 / 2 c^2) \approx 1 + \text{negligible}$, so relativistic $KE \approx$ classical KE .

Measurement Uncertainty and Its Impact

Sources of Measurement Error

- Instrument precision: radar guns, laser velocimeters, or other devices.
- Environmental factors: air resistance, vibrations, or electromagnetic interference.
- Human error during measurement.

Effects on Energy and Momentum Calculations

- Uncertainty in velocity propagates quadratically in kinetic energy calculations.
- For example, a ± 1 m/s uncertainty in velocity results in a change of approximately ± 11.7 Joules for the bullet's KE.
- For the electron, the energy change is negligible due to its tiny mass but is still subject to quantum measurement uncertainties.

Comparison Between Electron and Bullet

Scale and Behavior

- The electron's quantum nature dominates its behavior, requiring quantum mechanics for accurate description.
- The bullet's motion can be accurately described by classical mechanics.

Energy Differences

- The difference in kinetic energy magnitude is immense: approximately 2881 Joules for the bullet versus roughly 10-25 Joules for the electron.
- The electron's kinetic energy is negligible at this scale but is critical in quantum phenomena.

Practical Implications

- For macroscopic objects like bullets, measurement uncertainties are often small relative to the total energy.
- For electrons, even tiny uncertainties can significantly influence quantum calculations.

Conclusion

The comparison of an electron and a bullet traveling at the same speed highlights the fascinating differences in physical behavior at different scales. While classical mechanics provides an excellent approximation for the bullet, quantum mechanics governs the electron's dynamics, making measurement uncertainties more impactful at the atomic scale. Despite sharing the same velocity, their vastly different masses result in energy differences spanning many orders of magnitude. Understanding these principles is crucial in fields ranging from ballistics to quantum physics, emphasizing the importance of precise measurements and the underlying physics governing motion at all scales.

Frequently Asked Questions

What is the kinetic energy of the electron and the bullet given their masses and velocities?

The kinetic energy for each is calculated using $KE = \frac{1}{2} m v^2$. For the electron: $KE = 0.5 \times 9.11 \times 10^{-31} \text{ kg} \times (490 \text{ m/s})^2 \approx 1.09 \times 10^{-14} \text{ Joules}$. For the bullet: $KE = 0.5 \times 0.024 \text{ kg} \times (490 \text{ m/s})^2 \approx 2.89 \text{ Joules}$.

How does the mass difference between the electron and the bullet affect their momentum at the same velocity?

Momentum $p = m \times v$. The electron's momentum is approximately $4.46 \times 10^{-11} \text{ kg}\cdot\text{m/s}$, while the bullet's is $0.024 \text{ kg} \times 490 \text{ m/s} \approx 11.76 \text{ kg}\cdot\text{m/s}$. The much larger mass of the bullet results in significantly higher momentum despite having the same velocity.

What is the significance of measuring the velocity of both objects with an accuracy of within a certain margin?

Accurate velocity measurements allow precise calculation of kinetic energy and momentum, which are crucial in applications like particle physics experiments or ballistic analyses. Small errors can lead to significant differences in energy and momentum estimations.

How would a small error margin in velocity measurement impact the calculation of the kinetic energy for both objects?

Since kinetic energy depends on the square of velocity ($KE \propto v^2$), even a tiny percentage error in velocity measurement can cause a larger percentage error in KE. For example, a 1% error in velocity results in approximately a 2% error in kinetic energy.

Why is it important to consider the mass when analyzing the

motion of electrons and bullets at the same velocity?

Mass determines the amount of momentum and kinetic energy an object has at a given velocity. The electron's tiny mass results in negligible momentum and energy compared to the bullet, affecting their behavior in physical interactions and energy transfer processes.

In what practical scenarios might understanding the energy and momentum of an electron and a bullet at this velocity be relevant?

This knowledge is relevant in fields like particle accelerators, radiation physics, ballistics, and electromagnetic studies, where understanding how particles with vastly different masses behave at high velocities is crucial for safety, design, and analysis.

Additional Resources

An Electron and a 0.0240 Kg Bullet Each Have a Velocity of Magnitude 490 m/s, Accurate to Within — these are fascinating facts that exemplify the intriguing world of particle physics and classical mechanics. Whether you're a student delving into physics principles, an educator designing lesson plans, or a science enthusiast exploring the nuances of motion, understanding such details provides a window into the fundamental laws governing our universe. In this article, we will thoroughly analyze the implications of having an electron and a lightweight bullet each moving with a velocity of 490 m/s, focusing on their respective properties, the significance of measurement accuracy, and the broader physics principles involved.

Understanding the Objects in Question

The Electron: A Subatomic Particle

The electron is a fundamental particle, carrying a negative electric charge, with a mass approximately 9.109×10^{-31} kg. Its behavior at the quantum level is governed by quantum mechanics, but under certain conditions, classical physics can approximate its motion. When considering an electron moving at 490 m/s, we're typically referring to scenarios where its quantum nature remains significant but can be approximated by classical concepts, such as in electron beams or in certain experimental setups.

The Bullet: A Macroscopic Object

In contrast, a 0.0240 kg (24 grams) bullet is a macroscopic object, often made of metals like lead or copper. Its behavior at 490 m/s falls squarely within classical mechanics, where Newtonian physics accurately describe its motion, collisions, and energy transfer.

The Significance of Velocity at 490 m/sec

Velocity, a vector quantity indicating both speed and direction, is a core concept in physics. Here, both the electron and the bullet are said to have a velocity of 490 m/sec, which, while moderate for a bullet, is extremely high for an electron, given its quantum-scale mass.

Commonality in Velocity: A Starting Point

Having these two vastly different objects sharing the same velocity magnitude presents an interesting comparative scenario:

- Momentum comparison
- Kinetic energy analysis
- Measurement challenges and accuracy considerations

Measurement Accuracy: Why Does It Matter?

The phrase "accurate to within" hints at the importance of precision in experimental physics. In practice, measuring the velocity of particles or objects involves uncertainties due to limitations of instruments, environmental influences, and measurement techniques.

Types of Uncertainty

- Instrumental uncertainty: Limitations of measurement devices (e.g., radar guns, electron detectors)
- Environmental factors: Air resistance, electromagnetic interference
- Human error: Calibration issues, reading errors

Significance in Physics Calculations

Accurate measurements are essential because small variations can significantly impact calculations of momentum, energy, and related quantities. For instance, a ± 1 m/s uncertainty at 490 m/s represents about a 0.2% error, which is quite precise but still influential in detailed analyses.

Analyzing the Physics: Momentum and Kinetic Energy

Momentum (p)

Momentum is calculated as:

$$p = mv$$

where:

- m = mass of the object
- v = velocity

For the electron:

$$p_{\text{electron}} = (9.109 \times 10^{-31} \text{ kg}) \times 490 \text{ m/s} \approx 4.464 \times 10^{-28} \text{ kg}\cdot\text{m/s}$$

$$10^{-28} \text{ kg}\cdot\text{m/s}$$

\]

For the bullet:

\[

$$p_{\text{bullet}} = 0.0240 \text{ kg} \times 490 \text{ m/s} = 11.76 \text{ kg}\cdot\text{m/s}$$

\]

This stark difference illustrates how mass dominates momentum at the same velocity.

Kinetic Energy (KE)

Kinetic energy is given by:

$$KE = \frac{1}{2} mv^2$$

For the electron:

\[

$$KE_{\text{electron}} = \frac{1}{2} \times 9.109 \times 10^{-31} \text{ kg} \times (490 \text{ m/s})^2 \\ = 0.5 \times 9.109 \times 10^{-31} \times 240100 \approx 1.093 \times 10^{-25} \text{ J}$$

\]

For the bullet:

\[

$$KE_{\text{bullet}} = 0.5 \times 0.0240 \text{ kg} \times (490)^2 \\ = 0.012 \times 240100 \approx 2881.2 \text{ J}$$

\]

The contrast here is immense—while the electron's kinetic energy is minuscule, the bullet carries a significant amount of energy, readily capable of causing damage or transferring momentum in collisions.

Broader Implications and Applications

Quantum vs. Classical Mechanics

- Electron: Its behavior is predominantly quantum mechanical, with wave-particle duality, quantum states, and probabilistic properties. Precise measurement of its velocity involves quantum detection methods and is often subject to Heisenberg's uncertainty principle.
- Bullet: Its motion can be accurately described using classical mechanics. Measurement techniques include radar velocity guns, chronographs, or Doppler radar, with uncertainties manageable within specified tolerances.

Practical Contexts

- **Electrons in Technology:** Electron velocities are crucial in electron microscopes, cathode ray tubes, and particle accelerators, where precise control of electron beams is essential.
- **Bullets in Ballistics:** Understanding the velocity and accuracy of bullets is vital in forensic ballistics, military applications, and sports shooting, where accuracy within specific margins can be the difference between success and failure.

Challenges in Measurement Accuracy

Measuring the velocity of an electron to within a certain accuracy involves sophisticated equipment:

- **Time-of-flight measurements:** Using detectors that measure the time it takes electrons to traverse a known distance.
- **Electromagnetic spectrometers:** Using magnetic and electric fields to determine particle velocities based on their trajectories.

For macroscopic objects like bullets, common measurement techniques include:

- **Doppler radar:** Detects changes in frequency due to motion.
- **High-speed cameras:** Capture the projectile's motion frame-by-frame.
- **Chronographs:** Devices that measure the time it takes a projectile to pass between two points.

Limitations and Error Sources

- Detector resolution
- Environmental disturbances such as wind or electromagnetic interference
- Calibration errors
- Human reaction times in manual measurement techniques

Calculations Considering Measurement Uncertainty

Suppose the measurement of velocity is accurate to within ± 1 m/sec, i.e., the actual velocity could be between 489 and 491 m/sec. Here's how that impacts key quantities:

Electron Momentum Range:

$$p_{\min} = 9.109 \times 10^{-31} \times 489 \approx 4.454 \times 10^{-28}$$

$$p_{\max} = 9.109 \times 10^{-31} \times 491 \approx 4.474 \times 10^{-28}$$

Difference:

$$\Delta p \approx 2 \times 10^{-30} \text{ kg}\cdot\text{m/s}$$

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Bullet Kinetic Energy Range:

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$$KE_{\min} = 0.5 \times 0.0240 \times (489)^2 \approx 2872.9, \text{J}$$

\]

\[

$$KE_{\max} = 0.5 \times 0.0240 \times (491)^2 \approx 2889.3, \text{J}$$

\]

Difference:

\[

$$\Delta KE \approx 16.4, \text{J}$$

\]

These variations, while seemingly small, can be crucial in high-precision experiments or applications.

Final Thoughts: The Interplay of Scale and Measurement

The comparison between an electron and a 0.0240 kg bullet each having a velocity of 490 m/sec underscores the fascinating differences in scale and the importance of measurement accuracy:

- Scale: The electron's mass is orders of magnitude smaller, resulting in different dominant physical principles and measurement challenges.
- Measurement precision: Achieving accurate velocity measurements requires specialized techniques tailored to the object's scale.
- Physics principles: While classical mechanics describe the bullet's motion effectively, quantum mechanics govern the electron's behavior, especially at such high velocities relative to its mass.

Understanding these nuances enriches our appreciation for the physical universe's complexity and precision. Whether in fundamental research or practical applications, maintaining measurement accuracy within specified bounds is essential for advancing science and technology.

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